combustion technology

Basics

Combustion & burner technology
Heating equipment design

Reliability at work

BASICS OF COMBUSTION TECHNOLOGY

Combustion triangle

The combustion triangle represents the necessary conditions for combustion. All conditions must coincide at the same time and in the same place.

The three conditions in the combustion triangle are the following:

- Fuel
- Oxygen
- Heat (mechanical sparks, electricity)

Source: Wikipedia

As the mixing ratio is essential for meeting the three conditions to start the combustion process, it is considered a fourth condition.

Firing efficiency ηF

Firing efficiency describes the use of the heat arising from the combustion of a fuel at nominal load. Only the heat loss caused by the cooling of the flue gas down to ambient temperature is considered.

ηF = 100 % – qA (qA: Flue gas loss [%])

Approximate calculation using the following formula:

$$q_A = (\vartheta_a - \vartheta_l) \cdot \left(\frac{A2}{21 - O_2} + B \right)$$

A2 = 0,66 (Natural gas)
B = 0,009 (Natural gas)
θa – flue gas temperature [°C]
θl – Combustion air temperature [°C]
O_2 – Oxygen level in flue gas [%]

Air-fuel ratio λ

The air-fuel ratio λ is the ratio between the amount of supplied air l_0 and the theoretically required amount of air l_0,min

$$\lambda = \frac{l_0}{l_{0,\mathrm{min}}}$$

λ = 1 refers to the stoichiometric air-fuel ratio, meaning all fuel molecules react completely with atmospheric oxygen, without creating a lack of oxygen or residual unburned oxygen.

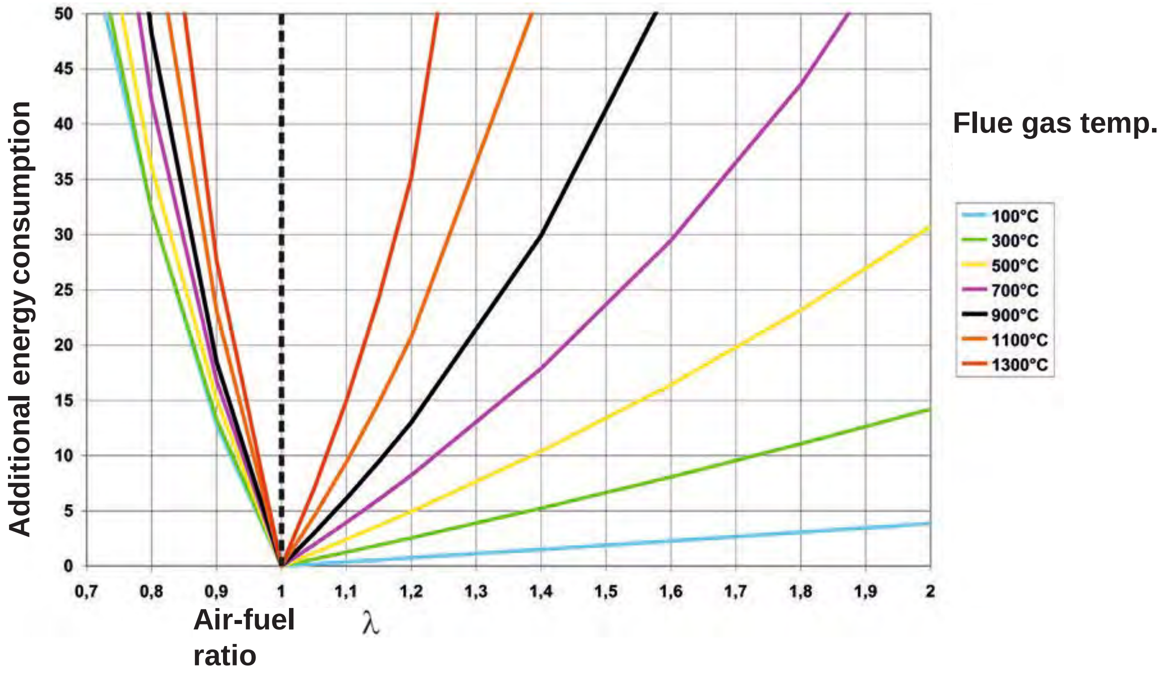
λ < 1 (i.e. 0.9) means “lack of air”

λ > 1 (i.e. 1.1) means “surplus of air”

An approximative calculation can be done through the residual oxygen content in the flue gas:

$$\lambda \approx \frac{21}{21-\kappa_{O2}}$$

Optimally, the residual amount of oxygen in the flue gas should be between 2.5 and 3.5%. A lambda which is too high leads to an excess consumption of fuel gas, which increases even further at higher application and flue gas temperatures.



BURNER TECHNOLOGY

Design features and function of a cold-air burner

The cold-air burner consists of a two-parts burner body, the combustion tube, a gas lance, and an electrode.

Combustion air flows via the connection pipe, through the air part, into the combustion tube and then through the swirl plate into the combustion chamber. The swirl plate swirls the combustion air, leading to intensive mixing with the combustion gas inside the combustion chamber. The combustion gas flows towards the swirl plate through the gas part and the gas lance via the connection pipe. At this point, the gas flow is separated. The main part of the combustion gas flows into the combustion chamber, where it is intensively mixed with the swirled combustion air. The smaller share of the combustion gas is led into the ignition chamber of the swirl plate and then ignited with high-voltage sparks.

Perfectly matched conditions inside the ignition chamber enable easy ignition and starting of the burner (cold start). The flame gases emit from the burner tube at high velocity.

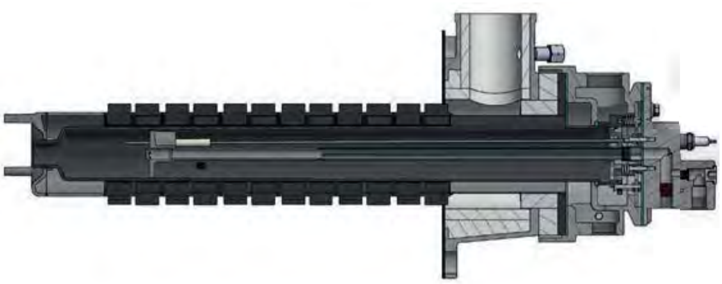
The waste gases emerging from the burner are vented separately.

Purge air is added to the combustion gas inside the gas part in metered quantities via a purge air nozzle. This makes for good ignition conditions. Moreover, it flushes the residual combustion gas left in the gas lance when the burner shuts-down, thus avoiding afterburning.

Upon request, NOXMAT high-velocity burners can also be equipped with a cooling air connector. Cooling air flows from the connector through the air part, directly through the combustion tube and into a radiant tube or into the furnace chamber.

Depending on the process, flame monitoring occurs via a flame monitoring current and a UV sensor, or via an ionization current and the electrode, which serves as both an ignition and an ionization electrode.

Design features and function of a recuperative burner



The recuperative burner is comprised of a three-part burner body, a recuperator, a burner tube, a gas lance, and an electrode, along with various other components.

Combustion air flows via a connected line through the air part and the recuperator and is preheated by utilizing the waste-gas heat. The majority of the combustion air (primary air) flows from the recuperator outlet through holes into the interior of the burner tube and, further, through the swirl plate into the combustion chamber. The smaller portion of combustion air (secondary air) exits the recuperator through the annular gap in the combustion-air chamber mouth and is mixed with the flame gases escaping from the combustion chamber.

The air guide plate splits-up the volumetric combustion-air flow as it enters the air part. Combustion air may flow either completely through the recuperator, or some portion of it may flow directly through the burner tube inside the burner. This is to protect the burner internals from overheating in case of very high thermal loads.

Fuel gas flows via a connected line through the gas part and the gas lance to the swirl plate. At this point, the gas flow is divided. The majority of the fuel gas flows into the combustion chamber, where it mixes with the intensively swirled combustion air. A smaller portion of the fuel gas is siphoned into the ignition chamber of the swirl plate and is ignited there by means of a high-voltage ignition spark. Precise conditions in the ignition chamber ensure successful, repeatable ignition of the burner, even from a cold start.

The flame gases escape with high velocity from the burner tube. They are mixing with secondary air, thus achieving complete combustion. Graded fuel-gas and combustion-air supplies affect a delayed combustion process, entailing a low combustion temperature and, thus, reduced NOx-emission.

Waste gas is flowing via the recuperator into the waste-gas part and finally exits the burner from there.

BURNER TECHNOLOGY

The waste gas conveys a part of its heat to combustion air in the recuperator to preheat the combustion air. Said preheating cycle entails fuel savings.

Purge air is supplied to fuel gas in the gas part through a purge-air nozzle in metered quantities to achieve excellent conditions for ignition. Further, said purge air is purging the gas lance to remove residual fuel gas in case of burner shutdown. So, any afterburning is precluded.

NOXMAT recuperated burners are equipped with a separate cooling-air connection. Cooling air is directly flowing from there through the burner tube into the radiant tube.

Flame monitoring is achieved either via the flame monitoring current of a UV-sensor, or via the ionization current of the electrode, which in this case performs both the ignition and ionization functions.

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Waste gas losses

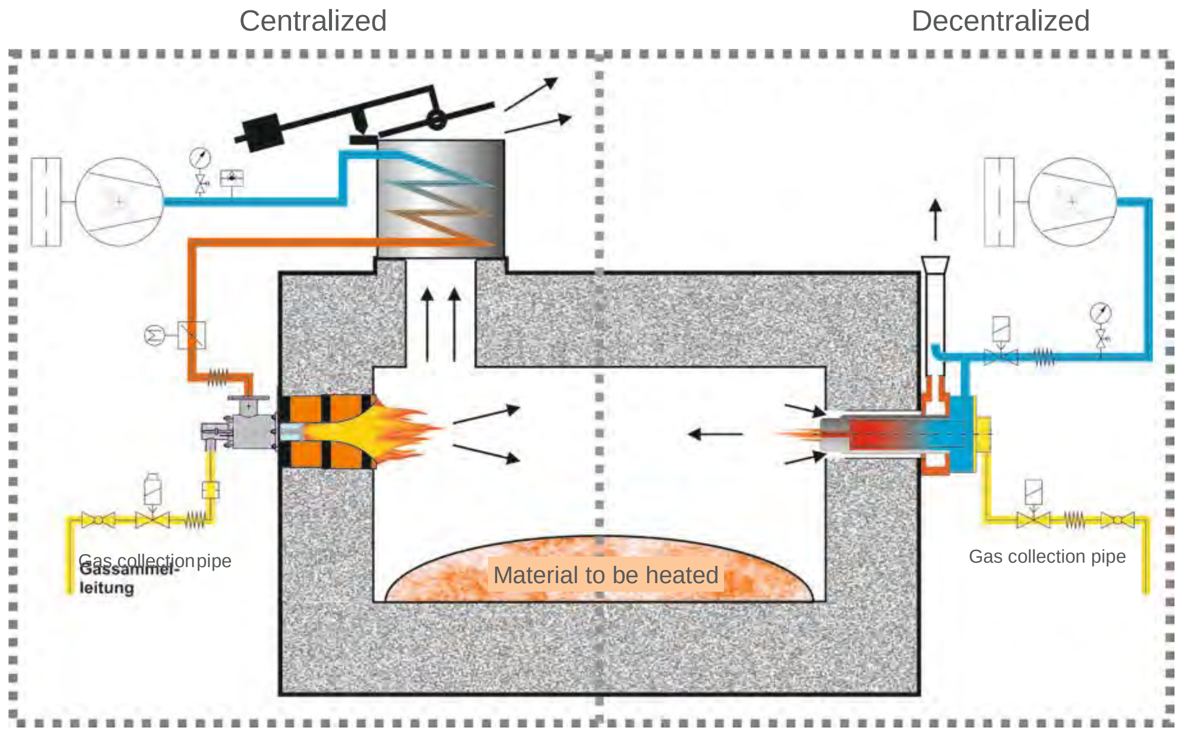
As the name suggests, a cold-air burner is operated without preheating the combustion air. This makes its set-up especially simple. The rising process temperature naturally leads to a rise in waste gas temperature and thus in waste gas loss. At furnace temperatures of 1000°C, the waste gas loss in case of direct heating is almost precisely 50%, meaning that only 50% of the energy supplied by the combustion gas is used for the heating of the furnace/material to be heated; the other 50% exits the furnace chamber completely unused. Firing efficiency thus is also 50%.

Heat recovery – Energy conservation through pre-heating of the combustion air

A very effective way to improve the efficiency is to preheat the combustion air through recuperated heat recovery from the waste gas. By reducing the waste gas temperature, the temperature of the combustion air is increased, thus directly enhancing firing efficiency.

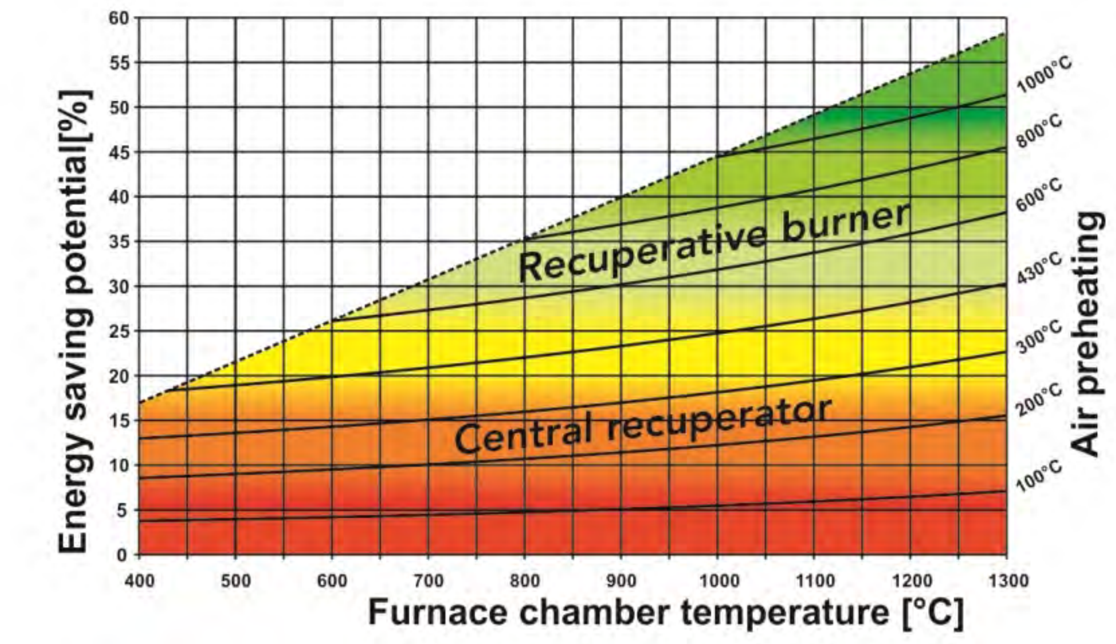
A reduction of the waste gas temperature by 100°C leads to an increase of firing efficiency of almost 6%.

Recuperated heat recovery can be centralized, meaning that the waste gases caused by the individual burners are led through one central heat exchanger (central recuperator); or it can be decentralized, meaning that each burner has its own heat exchanger (recuperator burner).

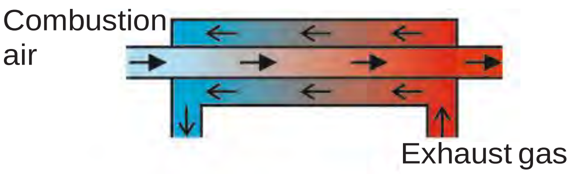


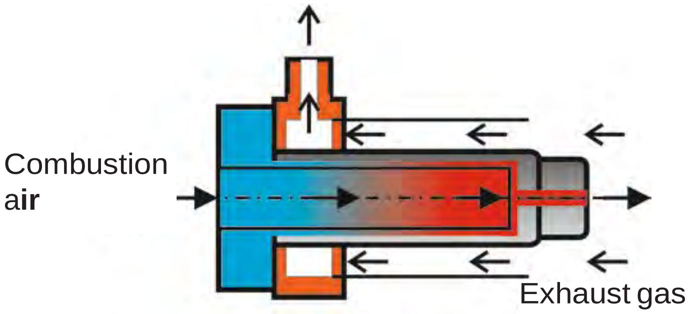
BURNER TECHNOLOGY

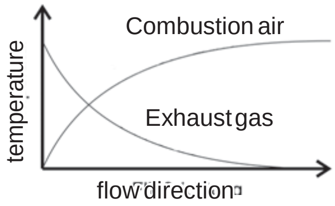
The number of central recuperators in use is quite high, even to this day. This option has several drawbacks, such as the necessity for hot air compensation as well as for a protection system for the recuperator. Moreover, all components of the combustion air supply system must be heat-resistant and designed for larger operating volume flows. Only rarely is this system capable of achieving combustion air temperatures of 400°C at the burner. Air preheating and thus energy savings are usually considerably higher for recuperator burners, as is shown in the following diagram:



The recuperator burner uses the very effective counter-flow principle, where waste gases transfer the largest possible share of their energy to the combustion air flowing the other way, which increases firing efficiency.





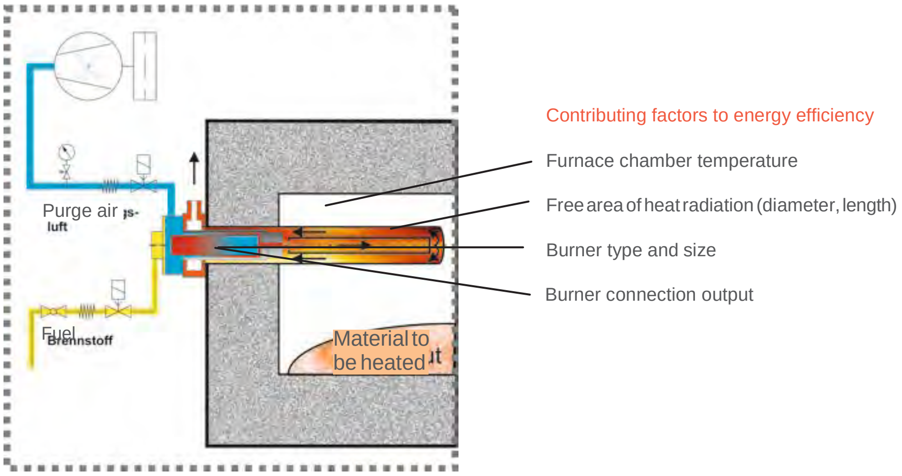


$T_{VL\ max} = T_{A\ max}{}^{*}$

(* at same thermal capacity flow of air and waste gas)

Factors impacting firing efficiency

In general, the objective for the operation of a burner is the highest possible efficiency in order to reduce fuel consumption and emissions. Firing efficiency, however, is not determined by the burner alone, but may also be impacted to a certain degree by other factors.

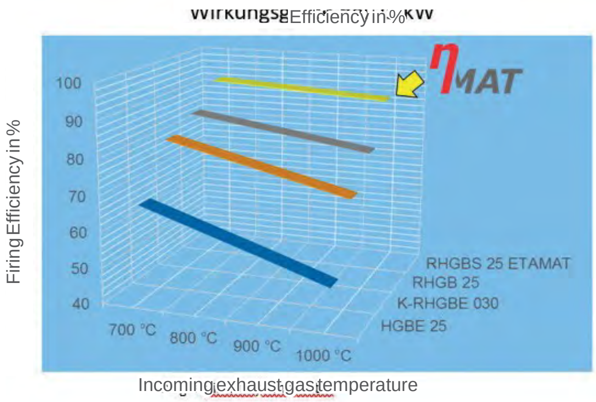


Basically, firing efficiency decreases when the temperature inside the furnace chamber rises. If other parameters remained the same, waste gas temperatures would increase.

A reduction of the burner capacity, while having a positive impact on firing efficiency, reduces the quality of the combustion and can cause higher emissions. Therefore, it is only recommended under certain conditions.

In indirect heating, the free area of heat radiation on the jacket tube is increased, which therefore increases efficiency as the heat transfer inside the furnace chamber improves. As a general rule, jacket tube sizes should be selected accordingly; the jacket tube must be sufficiently large.

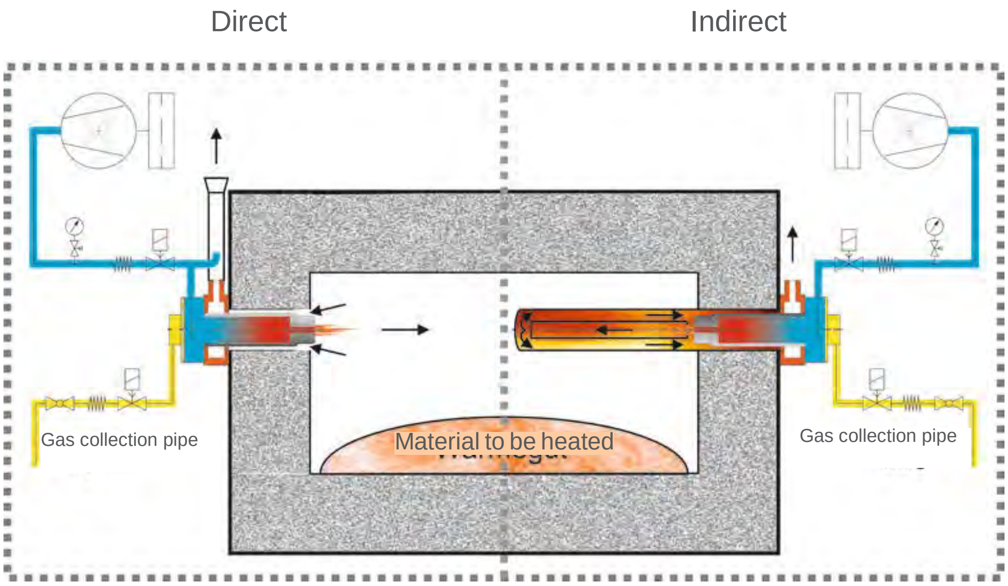
Naturally, the burner itself is of considerable significance. The diagram shows the different efficiencies of the different burner types depending on the waste gas temperature at inlet temperature.



SELECTION OF THE OPTIMUM HEATINGEQUIPMENT

1. Direct or indirect heating?

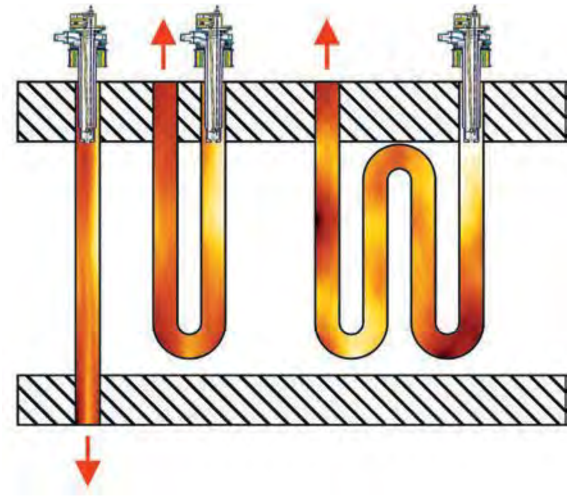
There is a principal distinction between direct and indirect heating. When designing a heat treatment plant, it must first be determined whether indirect heating is required or if direct heating is sufficient for the desired process.



- Direct impact of flame gases on the material to be heated
- High circulation inside the furnace chamber
- Waste gases must be retracted directly (via the ejector)
- i.e. Forging furnaces
- Common burner capacity 50-250 kW

- No direct impact of flame gases on the material to be heated
- No circulation inside the furnace chamber
- Waste gases exit the radiant tube (burner housing) automatically
- i.e. Heat treatment furnaces with protective gas atmosphere
- Common burner capacity 15-80 kW (straight radiant tube) or 120 kW (double p-tube)

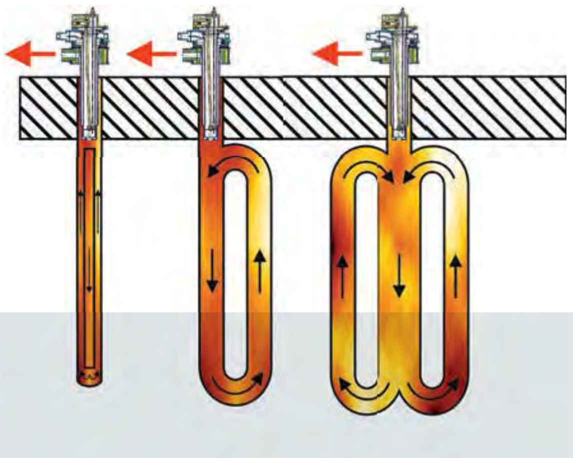
Radiant tubes without recirculation



Disadvantages to using radiant tubes without recirculation:

- Heat recovery is zero or is very limited (high waste gas temperature)
- Temperature distribution is not satisfactory

Radiant tubes with recirculation



Advantages to using radiant tubes with recirculation:

- Improved heat recovery due to integrated recuperator
- Burner momentum is used for recirculation
- 3- to 5-fold circulation of flue gases inside the radiant tube
- High circulation velocities lead to a temperature equalization and to a cooling of the flame

2. Preheated air or cold-air operation?

The next step is to decide whether the plant should be equipped with a comparatively simple cold-air burner or a highly efficient recuperative burner. In principle, either is possible.

As the name suggests, a cold-air burner is operated without preheating the combustion air and with accordingly low efficiency. However, it is considerably more economical to purchase. The preferred use of cold-air burners is for low-temperature plants, where heat recovery is fairly difficult anyway. If a cold-air burner is chosen for indirect heating, only non-recirculating radiant tubes are used.

Preheating the combustion air usually becomes worthwhile once furnace chamber temperatures exceed approx. 500°C. The easiest way to achieve this is by using recuperative burners. They are characterized by their compact shape and high energy efficiency. If used for indirect heating, so-called non-recirculating radiant tubes are installed.

Two-stage combustion is common for recuperative burners, meaning that the air flow volumes separates into primary and secondary air. Firing efficiency is accordingly high and emissions thus accordingly low. The so-called single-stage recuperative burner K-RHGBE is a simplified and ceconomical alternative model. Firing efficiency is still considerably higher than in cold-air burners, but the price is significantly below that of a “conventional” recuperative burner.

3. Steel or Ceramic?

The maximum application temperature for steel recuperator burners is 1,150°C.

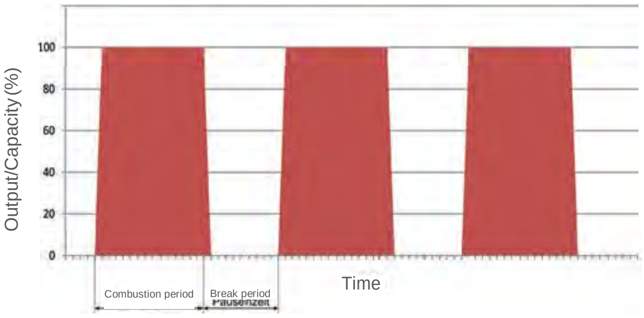
At higher application temperatures up to 1,300°C, ceramic recuperator burners must be used. In case of direct heating, this is more or less the temperature of the furnace chamber; however, such is not the case for indirect heating, as temperatures inside the radiant tube are often considerable higher than inside the furnace chamber. This distinction must be considered when designing the burner as well as the radiant tubes. In general, the thermal load on the burner and the radiant tube decreases if larger jacket tube surfaces are chosen, while also increasing firing efficiency.

4. Mode of operation: On/Off, High/Low, Continuous?

On/Off control mode

Recuperated burners usually operate in on/off control mode (standard application). This has several advantages:

- Cost-efficient application
- Simple configuration of the burners
- Max. momentum of the burners (temperature equalization)
- Burners always burn at the optimal point of operation



One advantage of the on/off control mode is made clear with the use of quick-release gas and air valves, which allow the burner to rapidly reach high-fire (optimal operation). In the case of direct heating, on/off control can enhance circulation inside the furnace, promoting temperature uniformity. Predictably, on/off firing is only possible for burners which display repeatable, reliable ignition. NOXMAT burners are perfect for on/off control, thanks to their patented ignition chamber. Combustion (on) and break (off) periods may be varied freely by the overarching furnace control system according to the application requirements; however, they should not fall below 15/5 seconds.

SELECTION OF THE OPTIMUM HEATINGEQUIPMENT

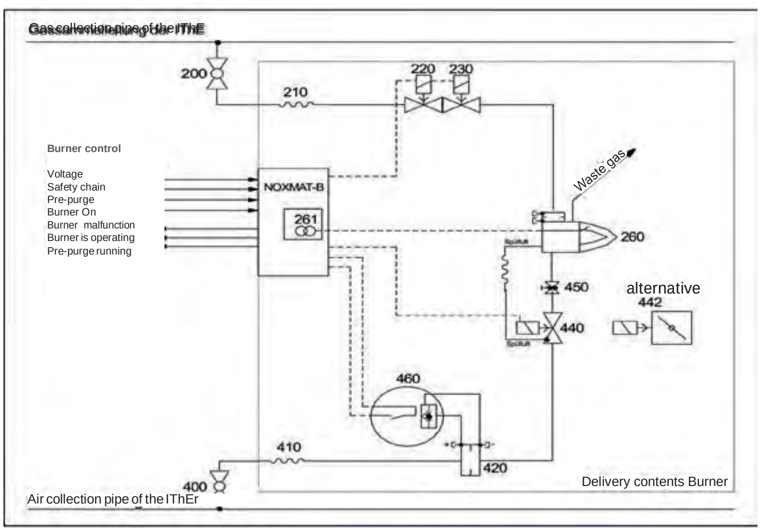


Image: Model process of an on/off control mode of a recuperative burner. The burner output is determined by the built-in gas nozzle.

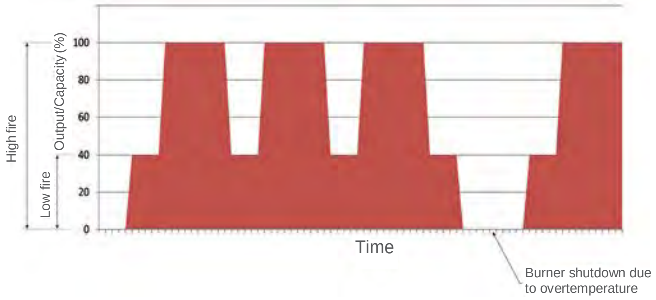
Key			
Gas		**Combustion air**	
200	Manual shut-off valve	400	Manual shut-off valve
210	Gas hose	410	Air hose
220	1. Shut-off valve without damping	420	Measuring orifice
230	2. Shut-off valve without damping	440	Air-solenoid valve without damping
260	Burner	alternative 442	Air-solenoid flap without damping
261	Ignition / Flame monitoring	450	Air setting mechanism
		460	Air pressure monitor

High/Low control mode

High/Low control mode is used relatively rarely these days. In this mode, the burner is usually not shut down at all (permanent operation), but switches between two levels depending on the heat requirements.

This mode used to be popular to guarantee constant positive pressure inside the combustion chamber when using direct heating, or for burners with poor ignition behavior, to reduce the probability of a fault when starting the burner. The o++verarching furnace control only shuts down the burner in case of over-temperature inside the combustion chamber.

This mode of operation may be implemented, for instance, when using two-stage valves.



Burner shutdown due to overtemperature

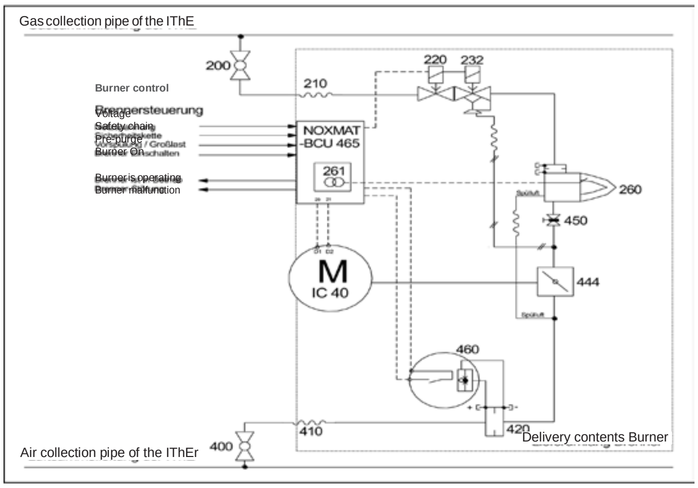


Image: Model process of a high/low control mode of a cold air burner. The burner output is determined by the furnace control.

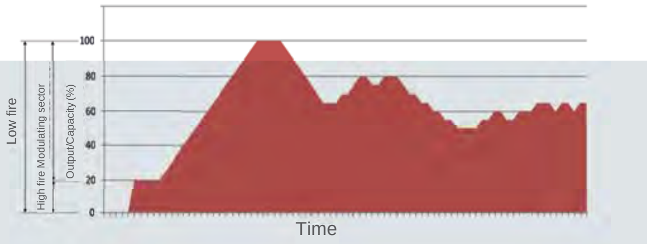
Key			
Gas		**Combustion air**	
200	Manual shut-off valve	400	Manual shut-off valve
210	Gas hose	410	Air hose
220	1. Shut-off valve without damping	420	Measuring orifice
230	2. Shut-off valve without damping	444	Air regulation valve / Air regulation flap
260	Burner	450	Air setting mechanism
261	Ignition / Flame monitoring	460	Air pressure monitor

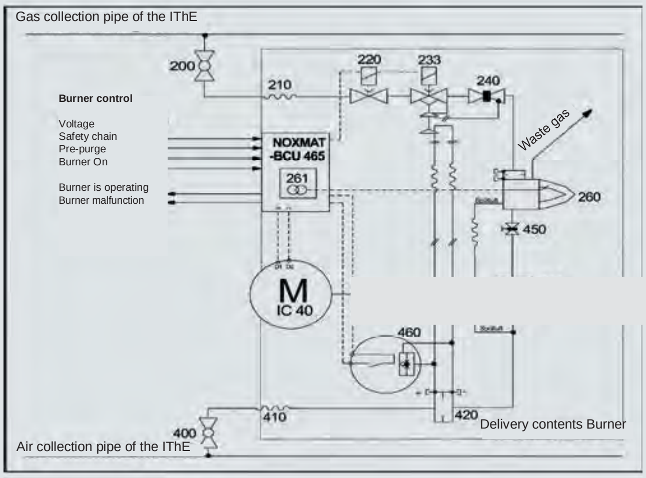
SELECTION OF THE OPTIMUM HEATING EQUIPMENT

Continuous control mode

Continuous control mode of a burner requires significantly more complex control engineering than on/off control. The burner is usually ignited at low low-fire and can be operated in continuous mode, depending on the heat requirement, at any possible power mode between high and low.

This mode of operation may be implemented by using an air flap whose opening angle can be varied depending on the heat requirement. The air flap must be activated separately by furnace control. The amount of gas is usually adapted automatically in mechanical compound with a ratio or flow volume controller. It ensures that the air-fuel ratio lambda remains as constant as possible at each power stage





Model process of a continuous control mode of a recuperated burner. The burner output is determined by the furnace control.

Key			
Gas		Combustion air	
200	Manual shut-off valve	400	Manual shut-off valve
210	Gas hose	410	Air hose
220	1. Shut-off valve without damping	420	Measuring orifice
233	2. Shut-off valve with air/gas ratio control	444	Air regulation valve / Air regulation flap
240	Setting mechanism for air/gas ratio control	450	Air setting mechanism
260	Burner	460	Air pressure monitor
261	Ignition / Flame monitoring		

PRODUCT OVERVIEW

Series RHGBS ***ETAMAT***
Recuperated high-velocity burner with metal foam recuperative for the indirect heating of industrial furnaces 15-35 kW

Series RHGB
Recuperated high-velocity burner with steel recuperative for the direct and indirect heating of industrial furnaces 7-250 kW

Series K-RHGB
Recuperated high-velocity burner with ceramic recuperative for the direct and indirect heating of industrial furnaces 9-250 kW

Series K-RHGBE
Recuperated high-velocity burner with ceramic recuperative combustion tube for the direct and indirect heating of industrial furnaces 9-100 kW

Series K-RHGB RN ***REMAT***
Retrofit recuperated high-velocity burner with ceramic recuperative for the indirect heating of industrial furnaces 13-25 kW

Series HGBE
High-velocity burner for the direct and indirect heating of industrial furnaces 9-160 kW

Steel or ceramic jacket radiant tubes for the indirect heating of industrial furnaces

Accessories for industrial heating systems (burner control units, combustion air fans, gas pressure measurement and control systems, etc.)

UNITS

Energy, Quantity of heat

Unit symbol	Designation of unit	J=Nm	kWs	kWh	kcal	R.deg C	BTU
1 J = Nm	Joule= Newton meter	1	0,001	$2,7778*10^{-7}$	$2,3885*10^{-4}$	0,12028	0,00095
1 kWs	kilowatt second	1000	1	$2,7778*10^{-4}$	0,238846	120,276	$3,7251*10^{-4}$
1 kWh	kilowatt hour	3 000 000	3600	1	859,845	432 991	3412,14
1 kcal	Int. Steam table calorie	4186,8	4,1868	0,001163	1	503,575	3,96381
1 R . grd	Gas constant	8,3142	0,00831	$2,3095*10^{-4}$	0,001986	1	0,00788
1 BTU	British thermal unit	1055,06	1,05506	0,000293	0,251995	126,963	1

Specific heat

Unit symbol	Designation of unit	J/kg deg C	kcal/kg	J/kg deg C	BTU/lb deg F
1 J/kg grd	Joule per kilogram per degree Celsius	1	$2,38844*10^{-4}$	$2,77778*10^{-7}$	$2,38844*10^{-4}$
1 kcal/kg grd	kilocalorie per kilogram per degree Celsius	4186,8	1	$1,163*10^{-3}$	1
1 kWh/kg grd	Kilowatt hour per kilogram per degree Celsius	$3,6*10^{6}$	859,845	1	859,845
1 BTU/lb deg F	British thermal unit per pound per degree Fahrenheit	4186,8	1	$1,163*10^{-3}$	1

Power

Unit symbol	Designation of unit	J/s = 1 W	kW	kcal/h	BTU/s	BTU/min	PS
1 J/s = 1 W	1 Joule per second = 1 Watt	1	0,001	0,86	$0,948*10^{-3}$	0,0569	$1,36*10^{-3}$
1 kW	kilowatt hour	1000	1	860	0,948	56,869	1,359
1 kcal/h	kilocalorie per hour	1,163	$1,163*10^{-3}$	1	$1,10*10^{-3}$	0,066	$1,58*10^{-3}$
1 BTU/s	British thermal unit per second	1060	1,06	0,252	1	60	1,43
1 BTU/min	British thermal unit per minute	17,58	0,01758	15,13	0,01667	1	0,0239
PS	Horsepower	735,48	0,735	0,176	0,697	41,827	1

Volume

Unit symbol	Designation of unit	cm^3	dm^3 = 1 l	m^3	in^3	ft^3	gal (US)
1 cm^3	Cubic centimeters	1	0,001	$1*10^{-6}$	0,061102	-	0,00026
1 dm^3 = 1 l	Cubic decimeter = liter	1000	1	$1*10^{-3}$	61,0237	0,03531	0,26417
1 m^3	cubic meter	$1*10^{-6}$	1000	1	61023,7	35,31	264,17
1 in^3	cubic inch	16,3871	0,01639	$16,39*10^{-6}$	1	0,00058	0,00433
1 ft^3	cubic foot	28316,8	28,3186	0,02832	17,28	1	7,48047
1 gal (US)	gallon (US)	3785,43	3,78543	$3,785*10^{-3}$	231	0,13368	1

Area

Unit-symbol	Designation of unit	mm²	cm²	m²	a	ha	km²	in²	ft²	sq. Mile
1 mm²	square millimeter	1	0,01	$1*10^{-6}$	-	-	-	$1,55*10^{-3}$	$1,08*10^{-5}$	-
1 cm²	square centimeter	10	1	0,001	-	-	-	0,155	0,00108	-
1 m²	square meter	$1*10^{6}$	10 000	1	0,01	0,0001	-	1550	10,7639	-
1 a	Ar	-	-	100	1	0,01	0,001	0,001	-	119,599
1 ha	hectar	-	-	10 000	100	1	0,01	-	107 639	0,00386
1 km²	square kilometer	-	-	-	10 000	100	1	-	-	0,3861
1 in²	square inch	$6,45*10^{2}$	6,4516	-	-	-	-	1	0,00694	-
1 ft²	square foot	$9,29*10^{4}$	929,03	0,0929	0,00093	-	-	144	1	-
1 sq. mile	square mile	-	-	25899,9	258,999	2,58999	-	-	-	1

Length

Unit-symbol	Designation of unit	mm	cm	dm	m	km	in	ft	yd	mile
1 mm	millimeter	1	0,1	0,01	0,001	-	0,03937	0,00328	-	-
1 cm	centimeter	10	1	0,1	0,01	-	0,3937	0,03281	-	-
1 dm	decimeter	100	10	1	0,1	-	3,937	0,3281	0,109362	-
1 m	meter	1000	100	10	1	0,001	39,37	3,28084	1,09362	-
1 km	kilometer	-	100 000	10 000	1000	1	39 370	3280,84	1093,62	0,62137
1 in	inch	25,4	2,54	0,254	0,0254	-	1	0,08333	0,0277778	0,07778
1 ft	foot	304,8	30,48	3,048	0,3048	-	12	1	0,33333	-
1 yd (UK)	yard (UK)	914,398	91,4398		0,914398	-	36	3	1	-
1 mile	statute mile	-	-	16 093,4	1609,34	1,609	63360	5280	1760	1

Weight, mass

Unit-symbol	Designation of unit	g	kg	t	oz	lb
1 g	gram	1	0,001	-	0,03527	0,0022
1 kg	kilogram	1000	1	0,001	35,274	2,20462
1 t	ton	-	1000	1	35274	2204,62
1 oz	ounce	28,3495	0,02835	-	1	0,0625
1 lb	pound	453,592	0,045359	0,00045	16	1

UNITS

Pressure

Unit symbol	Designation of unit	Pa= N/m^2	h Pa= mbar	bar	mH20	kgf/ m^2=at	atm	lbf/in^2 (psi)	lbf/ft^2 (psf)
1 Pa=1 N/m^2	Pascal	1	0,01	0,00001	0,0001	0,00001	-	0,00014	0,02089
1 mbar	millibar	100	1	0,001	0,0102	0,001	-	0,0145	-
1 bar	bar	100 000	1000	1	10,1972	1,01972	0,98692	14,5037	2088,54
1 m WS	Centimeter of water	9806,65	98,07	0,09807	1	0,1	0,09678	1,42233	204,816
1 kp/m^2=1 at	Technical atmosphere	98066,5	980,67	0,098067	10	1	0,96784	14,2233	2048,16
1 atm	Standard Atmosphere	101325	1013,25	1,01325	10,3323	1,03323	1	14,696	2116,22
1 lbf/in^2 (psi)	pound-force per square inch	6894,76	69,95	0,06895	0,70307	0,07031	0,06805	1	144
1 lbf/ft^2 (psf)	pound-force per square foot	47,8803	0,48	0,00048	0,00488	0,00048	0,00047	0,00694	1

Pipe sizing table (DIN 2440)

Nominal size		Outer diameter	Wall thickness	Inner diameter	Free cross-section	Volume	Surface	Weight of the smooth pipe
inch	mm	da≈mm	s mm	di≈mm	AF≈cm^2	V≈l/m	Ao≈m^2/m	≈kg/m
1/8"	6	10,2	2	6,2	0,3	0,03	0,0032	0,407
1/4"	8	13,5	2,35	8,8	0,61	0,061	0,042	0,65
3/8"	10	17,2	2,35	12,5	1,23	0,123	0,054	0,853
1/2"	15	21,25	2,65	15,75	2,02	0,202	0,067	1,22
3/4"	20	26,75	2,65	21,25	3,66	0,366	0,084	1,58
1"	25	33,5	3,25	27	5,8	0,58	0,106	2,44
11/4"	32	42,25	3,25	35,75	10,12	1,012	0,133	3,14
11/2"	40	48,25	3,25	41,25	13,72	1,372	0,152	3,61
2"	50	50	3,65	42,5	22,06	2,206	0,189	5,1

CONVERSIONS

Temperature	ϑ ° Celsius	T Kelvin	t ° Fahrenheit
Degrees Celsius °C	ϑ	T-273,16	5/9(t-32)
Degrees Kelvin K	ϑ+273,16	T	5/9(t-455,67)
Degrees Fahrenheit °F	9/5*ϑ+32	9/5*T-459,67	t

Temperature	°C	T	°F
1 °C	1	273.16	33.8
1K	-273.16	1	-239.36
1°F	-17.22	255.93	1

Density	1 g/cm^3	lb/cu. inch	lb/cu. foot
1 g/cm^3	1	0.03613	62.428
1 pound/cubic inch	27.68	1	1728
1 pound/cubic foot	0.01602	5,79*10-4	1

c	N	kN	MN
1 N	1	10^{-3}	10^{-6}
1 kN	10^{3}	1	10^{-3}
1 MN	10^{6}	10^{3}	1

Time	s	ns	µs	ms	min
1 s	1	10^{9}	10^{6}	10^{3}	$16,66*10^{-3}$
1 ns	10^{-9}	1	10^{-3}	10^{-6}	$16,66*10^{-12}$
1 µs	10^{-6}	10^{3}	1	10^{-3}	$16,66*10^{-9}$
1 ms	10^{-3}	10^{6}	10^{3}	1	$16,66*10^{-6}$
1 min	60	$60*10^{9}$	$6*10^{6}$	$6*10^{3}$	1

GENERAL INFORMATION

Atmospheric pressure	Pressure	
Meters above sea level m	Torr	mbar = h Pa
0	760	1013
200	742	989
400	724	966
600	707	943
800	690	921
1000	673	899
1200	657	876
1400	641	854
1600	626	835
1800	611	851
2000	596	795
2200	581	775
2400	567	756
2600	553	737
2800	539	719
3000	525	701
3500	493	657
4000	463	616
5000	405	540
10 000	198	264
20 000	41	55

Temperature		
K	°C	°F
0	-273	-460
	0.01602	5,79*10-4
273	0	32
373	100	212
673	400	752
873	600	1112
1073	800	1472
1173	900	1652
1223	950	1742
1273	1000	1832
1323	1050	1922
1373	1100	2012
1423	1150	2102
1473	1200	2192
1523	1250	2282
1573	1300	2372

NOx values in different elements

Waste gas - Volume				Energy (Natural gas H)		
ppm at 3% O2	ppm at 5% O2	mg/m^3 at 3% O2	mg/m^3 at 5% O2	mg/kWh	mg/MJ	#/MMBTU
10	9	21	18	20	6	0.01
20	18	41	36	41	11	0.03
30	27	62	55	61	17	0.04
40	36	82	73	81	23	0.05
50	44	103	91	102	28	0.07
60	53	123	109	122	34	0.08
70	62	144	128	142	40	0.09
80	71	164	146	163	45	0.11
90	80	185	164	183	51	0.12
100	89	205	182	204	57	0.13
120	107	246	219	244	68	0.16
140	124	287	255	285	79	0.18
160	142	328	292	326	90	0.21
180	160	369	328	366	102	0.24
200	178	410	364	407	113	0.26
250	222	513	456	509	141	0.33
300	267	615	547	611	170	0.39
350	311	718	638	712	198	0.46
400	356	820	729	814	226	0.53
450	400	923	820	916	254	0.59
500	444	1025	911	1018	283	0.66
600	533	1230	1093	1221	339	0.79
700	622	1435	1276	1425	396	0.92
800	711	1640	1458	1628	452	1.05

CUSTOMER QUESTIONNAIRE

	Burner request							
0	Company							
	Project / Operator							
	Furnace type							
	Operation temperature							
			min		°C	max		°C
2	Gas type							
		Natural gas (NG):		Liquefied petroleum gas		Other		
3	Burner type							
	Burner quantity		Amount/Pieces		Burner connection value			kW
	Mounting position of the burner				horizontal		vertical	
	Cooling air connection at the burner				with		without	
4	Burner contro		Yes		No			
	Profibus		Yes		No			
	Profinet		Yes		No			
	Mode of operation:		On / Off		High / Low:		Continuous	
5	Magnet valves / flaps			Keine Vorgabe:		Manufacturer		
6	Radiant tube heating			Ja		No		
	Radiant tube type:		Straight:		P-type:		Double-P-type:	
			U-type:		Other			
	Radiant tube must be included			Yes		No		
	Outer diameter							
	nner diameter							
	Total length							
	Free length of heat radiation:							
	Flame tube must be included			Yes		No		
7	Comments							
8	Customer		Date:					
			Company:					
			Name					

combustion technology

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